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High-energy gamma-rays and positrons from 5.3 h Tl^{198}

By R. K. GUPTA,[1] J. SVEDBERG and G. ANDERSSON

With 2 figures in the text

ABSTRACT

Scintillation spectrometer studies of mass-separated Tl^{198} sources have shown transitions of 2.01, 2.45 and 2.78 MeV and probably others of 1.6, 1.8 and 2.2 MeV to be present in Hg^{198}. Results of gamma-gamma coincidence measurements form the basis for a preliminary discussion of the level scheme. The end-point energy of the positron spectrum has been determined as 2.44 ± 0.08 MeV.

1. Introduction

Energy levels in Hg^{198} are reached both by the negatron decay of 2.7 d Au^{198} and by the positron and electron capture decays of 5.3 h Tl^{198} and 1.9 h Tl^{198m} [1]. From the Au side only three gamma-rays have been found, establishing the following level sequence: 0+ (ground state), 2+ (412 keV), and 2+ (1089 keV). In contrast to this simple picture, the Tl^{198} decay feeds a most complicated level system [1, 2], largely as a consequence of the higher disintegration energy available in this case. From beta-decay systematics the energy difference between the 5.3 h ground state of Tl^{198} and the stable Hg^{198} is expected to be about 3.5 MeV [1]. This was even supported by preliminary positron measurements [3]. Prior to the present investigation, however, the highest energy transition reported in Hg^{198} was only about 1.4 MeV. Thus it was considered worthwhile to complement the conversion electron studies of Tl^{198} in progress at this Institute by a special investigation of the high-energy gamma-spectrum, using scintillation techniques, and in this connection to try to confirm the disintegration energy by measuring the positron spectrum more carefully.

2. Source preparation

The sources were prepared by electromagnetic mass separation, either of Tl obtained as the decay product of Pb, chemically isolated after Tl (p, xn) reactions in the Werner synchrocyclotron, or of the isolated Pb directly. The techniques have been described elsewhere [2, 4, 5]. It may be worth pointing out, however, that the 1.9 h isomeric state is not fed from 2.4 h Pb^{198} and thus was not present in the samples.

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[1] On deputation from Tata Institute of Fundamental Research, Bombay, India.

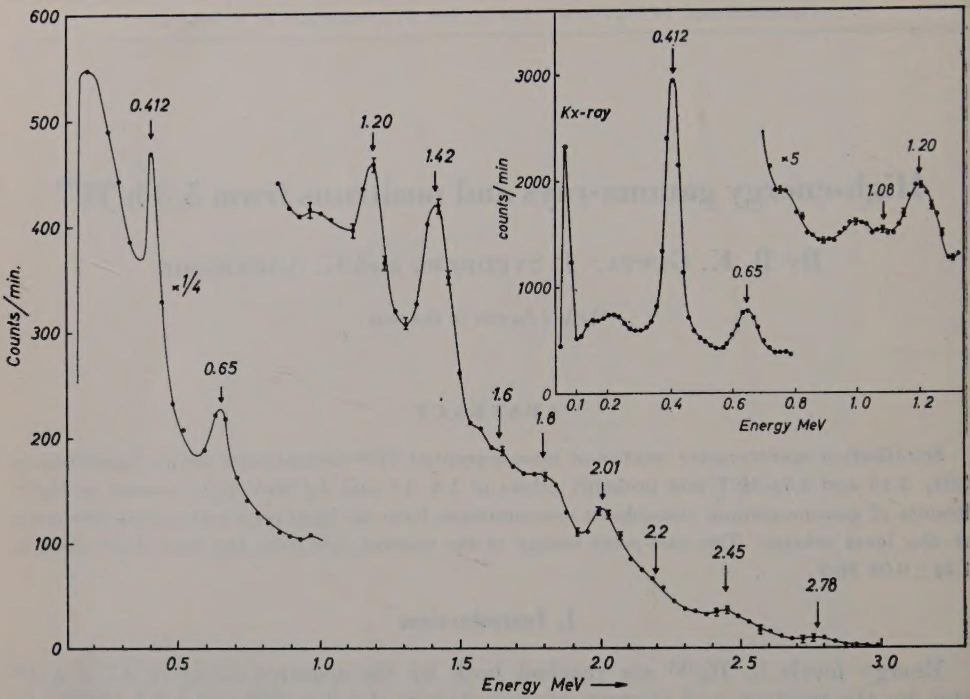

Fig. 1. Scintillation spectrogram of 5.3 h Tl^{198} with a 1 cm lead absorber in front of the 3″ × 3″ crystal. The inset shows the low energy part measured without the absorber.

3. Scintillation spectrum

The gamma-spectrum of 5.3 h Tl^{198} was studied with a scintillation spectrometer at the Nobel Institute of Physics,[1] using a 3″ × 3″ NaI(Tl) crystal and a Hutchinson-Scarrott type multi-channel analyser. In order to avoid overloading of the electronics, the intensities of low energy γ-rays were reduced by inserting 1 cm of lead between source and crystal. The source was placed at a distance of 10 cm from the crystal.

Mass-separated sources of Pb^{198} were allowed to decay for about 6 hours, in order to enhance 5.3 h Tl^{198} at the cost of 2.4 h Pb^{198}. The half-lives of the various photopeaks were checked by studying the scintillation spectrum at 5-hour intervals for about 20 hours.

A scintillation spectrogram of Tl^{198} obtained in this way is shown in Fig. 1. Also included is the low energy part of the spectrum, studied with a small portion of the same source and without the lead absorber.

The energies and intensities of the photopeaks recorded in the sepctrograms are summarized in Table 1. Some of the lines have been identified with transitions earlier assigned to the decay of Tl^{198}.

The intensities given in the table have estimated error limits of about 10 %. There are indications of photopeaks also at about 1.6, 1.8 and 2.2 MeV (Fig. 1)

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[1] We are indebted to Prof. M. Siegbahn and his collaborators for the use of this instrument.

Table 1.

Photopeak energy (keV)	Relative intensity	Identification (refs. [1] and [2])
412	100	412
650	44	635, 676
1080	3	1089
1200	24	1198
1420 ± 20	27	(1404), 1424, 1438, 1450
2010 ± 50	17	
2450 ± 50	6	
2780 ± 50	2	

but the resolution was not good enough to warrant the inclusion of their energies and intensities in the table. It should be remarked, however, that a 1515 keV conversion electron line assigned to the decay of Tl^{198} by Jung [2] may be the *K*-line of the 1.6 MeV transition.

4. Gamma–gamma coincidences

A coincidence scintillation spectrometer at the Physics Department of this University[1] was used to get information about possible cascade relationships. The coincidence resolving time was $2\tau = 30$ ns.

The 412 keV photopeak seems to be in coincidence with the entire scintillation spectrum up to 2 MeV, as the coincidence spectrum was found to look essentially the same as a single spectrum, except for the lines being better resolved. Because of the low intensity of photopeaks above 2 MeV it was not possible to decide whether the (2.2), 2.4, and 2.8 MeV γ-rays are in coincidence with the 412 keV transition or not.

With the 650 keV photopeak in the gate, peaks at 1.2 and 1.4 MeV, but no higher energy peaks, were seen in the coincidence spectrum. A closer study, keeping the gate at 1.2 MeV and 1.4 MeV, respectively, and measuring the spectrum around 650 keV, indicated coincidences only with the low energy side of the 650 keV photopeak. This would suggest that the 635 keV transition is in coincidence with the two high energy photopeaks, while the 676 keV transition is not.

Coincidence information was further obtained by measurements with a well-type $2'' \times 2''$ NaI(Tl) crystal. Sum peaks were indicated at 1090, ~1600, ~1850, ~2400 and ~2800 keV.

5. Discussion of Hg^{198} levels

From the complexity of the conversion electron spectrum [2] it seems very probable that all peaks found in the gamma-ray spectrum are more or less composite. In this situation one has to be very careful in drawing conclusions from the present coincidence data. There is, in fact, little meaning in attempting to

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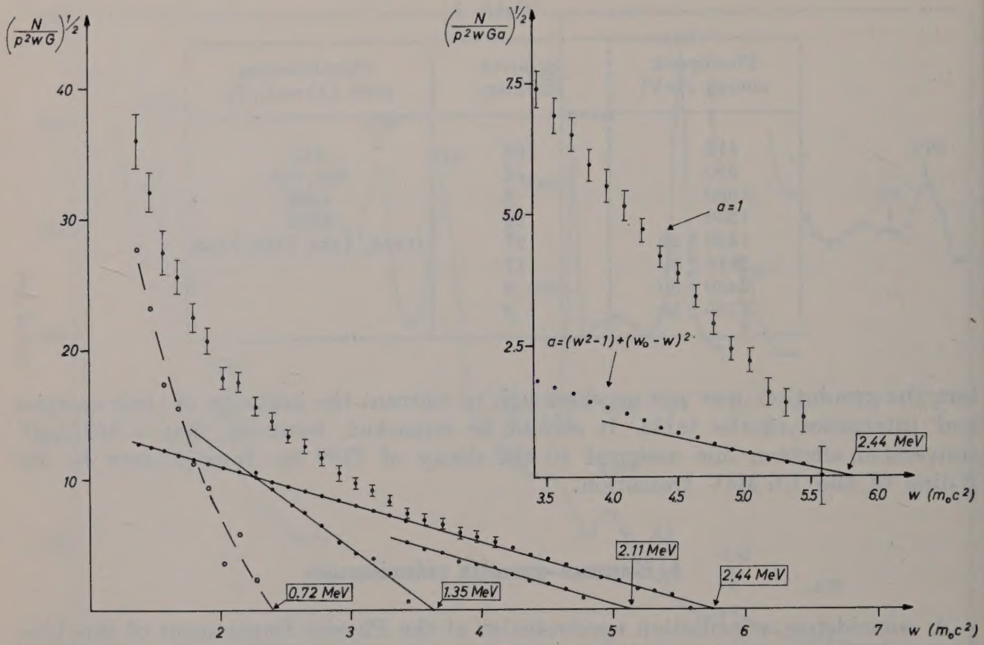

Fig. 2. Fermi analysis of the Tl^{198} positron spectrum, assuming unique first forbidden shape ($\Delta I = 2$, yes) for the most energetic component and allowed shape for the others. The inset shows the high energy part of the spectrum in larger scale. Notations according to ref. [7].

construct a level scheme without electron–electron coincidence information. Besides the well-known first and second excited states at 412 and 1089 keV, however, additional levels find some support by the following interpretation of energy sums in terms of transition energies derived from conversion electron data [1, 2]:

1610 keV ($= 412 + 1198$); γ–γ coincidence 412 keV–1.20 MeV; ~1.6 MeV sum peak.

1848 keV ($= 1610 + 238 \approx 412 + 1438$); γ–γ coincidence 412 keV–1.42 MeV; ~1.85 MeV sum peak.

2483 keV ($= 1848 + 635 = 412 + 1198 + 238 + 635 \approx 412 + 1438 + 635$); γ–γ coincidence 635 keV–1.20 and 1.42 MeV; also 412 keV–~2 MeV; ~2.4 MeV sum peak.

6. Positron spectrum

The two-directional focusing beta-spectrometer of the Institute [6] was adjusted to about 2% transmission and the positron spectrum studied with a Tl^{198} source. A measure of the total positron intensity was obtained from a comparison with the *K*-line of the 412 keV transition, giving $\Sigma\beta^+/K412 \approx 0.3$.

A Fermi plot assuming allowed shape showed the spectrum to be complex, but the resolution of the curve into its components was not obvious. Two branches corresponding to end-point energies of 2.4 ± 0.1 and 1.4 ± 0.1 MeV seemed to fit the upper part of the curve rather well. These end-point energies, however, are somewhat difficult to reconcile with the present knowledge of levels in Hg^{198}. It is true, that the energy difference agrees within the limits of error with the energy of the second excited 2+ level (1.089 MeV), indicating branches to this level and to the ground state. But then the question arises, why there is no feeding of the first excited 2+ level, which is expected to be favoured in this decay (cf. Tl^{200} [1]).

Thus the high-energy part of the spectrum was studied in more detail. As shown by the $a=1$ plot in the inset of Fig. 2, no further complexity could be established with certainty. However, the application of a correction for unique first forbidden shape, which should characterize the 2− −0+ ground state branch, leads to a very tentative resolution of the curve, also indicated in the inset. The main part of Fig. 2 illustrates the full Fermi analysis, assuming unique first forbidden shape for the most energetic component and allowed shape for the others. Using weighted least squares treatment, the following energies are obtained: 2.44 ± 0.08, 2.11 ± 0.07, 1.35 ± 0.11 and about 0.72 MeV.

The first three components mentioned may represent feeding of the ground state, the 412 keV 2+ level and the 1089 keV 2+ level, even if the energy agreement is by no means convincing. Their relative intensities as obtained from the Fermi analysis are about 1.4, 1.2 and 1.0, respectively.

It seems probable that the lowest-energy component is still complex, but no further analysis has been attempted because of the uncertainty of the points after repeated subtractions. There is no obvious suggestion as to what levels are fed by this part of the positron spectrum, which is remarkably strong (relative intensity $=0.4$) in wiew of the low energy. In this connection the appearance of a 3− level at about 2 MeV in Hg^{200}, recently reported from angular correlation studies [8], is of great interest. A corresponding level in Hg^{198}, leading to an allowed positron branch from the 2− ground state of Tl^{198}, could account for the main part of the 0.72 MeV component.

As already pointed out, the above analysis of the positron spectrum is rather ambiguous and largely based on the expected presence of a ground state branch. It is quite apparent, that a reinvestigation is desirable, using a higher transmission spectrometer and preferably positron–gamma coincidence techniques. The only conclusion that can be drawn with confidence from the present study is that the total beta disintegration energy of 5.3 h Tl^{198} is $\geqslant 3.46 \pm 0.08$ MeV, which at least does not contradict the value suggested from systematics [1].

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